TITLE OF THE INVENTION

01 Linear Engine and Housing for Engine

BACKGROUND OF THE INVENTION

02 This invention relates particularly to linear engines, that is, motors and pumps of the type that have a reciprocating piston confined within a housing, the piston being driven by a magnetic field generated by a coil or coils disposed around the housing, as well as other engines.

03 Various linear engines are known, as for example shown in US Patents 4687054, 3910729, 6,092,999, 6127750, 5083905, 4509001, 4541787, 4965864, 4692673, 5924975 and Eureka November 1997 Article "Shuttling Magnet Ensures Efficient Gas Compression.

SUMMARY OF THE INVENTION

04 This invention is directed towards a linear engine that, as with the references cited above, provides a simple, low maintenance, pump or motor (engine).

05 Therefore, according to an aspect of the invention, there is provided an engine, comprising a tubular housing, axially spaced electromagnetic coils disposed around the tubular housing, a piston disposed within the tubular housing, the piston including magnetic elements, and a drive circuit electrically connected to the first and second electromagnetic coils for sequentially energizing the first and second electromagnetic coils to move, as for example reciprocate, the piston within the tubular housing. In a first aspect of the invention, a magnetic sleeve is disposed within each coil, with the piston being arranged to pass through the magnetic sleeves during operation and the magnetic sleeves being separated by nonmagnetic material. In a further aspect of the invention, the magnetic sleeves each form part of the tubular housing. In a further aspect of the invention, sealed bearings at each end of the piston define a sump for retaining lubricating oil within a reduced diameter portion of the piston. In a further aspect of the invention,

the sealed bearings each comprise axially spaced circumferentially extending ribs, adjacent ribs being separated by a gap for receiving a sealing element.

06 These and other aspects of the invention are described in the detailed description of the invention and claimed in the claims that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

07 There will now be described preferred embodiments of the invention, with reference to the drawings, by way of illustration only and not with the intention of limiting the scope of the invention, in which like numerals denote like elements and in which:

Fig. 1 is a cross-section of a first embodiment of a linear engine according to the invention;

Fig. 2 is a cross-section through an end of a second embodiment of a linear engine according to the invention;

Fig. 3 is a cross-section of a third embodiment of a linear engine according to the invention;

Fig. 4 is a perspective exploded view of the embodiment of Fig. 1;

Fig. 5 is a section through a piston for use with the linear engine of Fig. 1;

Figs. 6A, 6B and 6C are sections through alternative embodiments of the piston of Fig. 5; and

Figs. 7A and 7B are perspectives, partly exploded, showing the design of alternative sleeves for use in the linear engine of Fig. 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

08 In this patent document, “comprising” means “including”. In addition, a reference to an element by the indefinite article “a” does not exclude the possibility that more than one of the element is present.

09 As shown in Figs. 1 and 4, a linear engine 10 is formed around a tubular housing 12 between a pair of end plates 14, 16 with a central flange 18. Electromagnetic coils 20, 22 are disposed around the tubular housing 12, each coil being made for example by winding a wire around the tubular housing 12. The coils 20, 22 are axially spaced from each other along the housing 12. The size of the gap between the coils 20, 22 is variable provided there is an unmagnetized portion between the coils 20, 22. A piston 24 is disposed within the tubular housing 12. The piston 24 includes magnetic elements, such as by being made of a magnetic material, or by having magnets carried by the piston 24. A drive circuit 26, incorporating a conventional power supply, is electrically connected to both electromagnetic coils 20, 22 for sequentially energizing electromagnetic coils 20, 22 to reciprocate the piston 24 within the tubular housing 12. Drive circuits for such linear motors are known in the art and need not be further described here in detail. Rods 31, with suitably threaded ends and bolts, not shown, may be used to secure the housing 12 together, although any of various ways known in the art could be used to secure the structure together.

10 In an embodiment of one of the inventions described in this patent document, magnetic sleeves 30, 32, for example made of steel, are each disposed inside a respective electromagnetic coil 20, 22, with the piston 24 being arranged to pass through the magnetic sleeves 30, 32 during operation. The magnetic sleeves 30, 32 are separated from each other by non-magnetic material, such as a further sleeve 34, which for example may be ceramic. As shown in Figs. 1 and 4, the sleeves 30, 32 and 34 may be correspondingly stepped for ease of fitting the parts together. As shown, therefore in Figs. 1 and 4, the magnetic sleeves 30, 32 each form part of the tubular housing 12.

11 In a further embodiment shown in Fig. 5, a series of electromagnetic coils 50, 52 and 54, with corresponding magnetic sleeves 60, 62 and 64 are provided spaced axially along the housing 12, and spaced by non-magnetic sleeves 56, 58, for example made of ceramic. The remaining components of the linear engine of Fig. 5 are designed in like manner to the components of Figs. 1 and 4, with the drive circuit being electrically

connected to the three electromagnetic coils for sequentially energizing the three electromagnetic coils 50, 52, 54 to reciprocate the piston 24 within the tubular housing 12.

12 In a further invention, the piston 24 is provided with a sump. The piston 24 has a bearing 70 extending circumferentially around one end of the piston 24, and another bearing 72 extending circumferentially around the other end of the piston 24. The bearings 70, 72 are axially spaced apart along the piston 24, with the piston 24 having reduced diameter, in relation to the diameter of the piston at the bearings 70, 72, between the bearings 70, 72 to define a lubricating sump 74. The sump 74 is of sufficient volume to hold a lubricating amount of oil, and in operation is at least partially filled with lubricating oil. As shown particularly in Fig. 5, the bearings 70, 72 may be each sealed by O-rings, gaskets or other sealing elements (not shown) placed in circumferential grooves 76 between circumferential ribs 78. The oil in the sump 74 lubricates the bearings 70, 72. The bearings 70, 72 preferably fit with a close tolerance within the housing 12, being separated by a suitably small gap.

13 The linear engine 10 described here may act as a pump or compressor. As a pump or compressor, the linear engine 10 may be configured one or more inlet and outlet valves 80, 82 respectively and control mechanisms (conventional and not shown) to actuate the valves so that the tubular housing or cylinder 12 and its contained piston 24, when the piston is moved within the cylinder, perform the function of a pump or a compressor. The linear engine 10 may also be fitted with a rod or drive shaft 84 as shown in Fig. 2 on the rotor (piston 24) to permit the transmission of the rotor's linear motion into useful energy in the form of a driven flywheel, for instance, or drive gear or pulley.

14 The electromagnets 20, 22 fixed adjacent to the cylinder 12 within which is deployed the cylindrical shaft or piston 24, for example a permanent magnet may be energized by AC or DC current controlled by a master on/off switch, through

drive/control circuit 26, whose purpose and configuration is to control the induction of magnetic field(s) at the electromagnets of suitable polarity, intensity, and duration.

15 The sump 74 provides an oil reservoir with suitable sealing and refilling means to provide lubrication to the shaft (piston 24) within the electromagnet-containing barrel/cylinder 12 of the body of the mechanism. The oil reservoir 74 may, but does not necessarily, provide a damper or an energy store or bumper for the cylinder as well as providing lubricant, if desirable, by pressure-sealing the sump. This method of lubrication provides for friction-reduction and some cooling to the cylinder 12 and shaft 24. A smaller diameter shaft could be deployed within a different system of bearings suspended centered within the cylinder containing the electromagnets, where the lubricant was provided by a sump at one end of the cylinder, and suitably sealed from splashing or other loss.

16 There may be other features in such an exemplary motor, such as the provision of bumpers or motion-limiting means to avoid having the pump piston or the shaft invade the pump cylinder or the oil reservoir in an unwanted way, which are not specifically described here, but would be apparent to one skilled in the art.

17 A further liquid lubricant-filled sump 86 is defined by the gasket/ring around the linear motor's rotor which is slidingly sealed within the motor's stator. The piston 24 is preferably a circular cross-sectioned rotor deployed within a fitting cylinder which is the internal cavity of the motor's stator(s)), configured such that the rotor is piston-like and the stator is sleeve or cylinder-like to apply and control lubricant. The sump 86, if pressurized, may be relied upon as an improved replacement for the wearable springs used in prior art reciprocating linear motors to return the piston to its starting position within a work cycle. However, the piston's return to start may as well, in one embodiment, be accomplished by the deployment of two stators (one at each end of the cylinder within which the rotor is deployed) each energized in a timed cycle to drive the

piston/rotor from one end to the other, in which case a return spring or pressured closed cylinder means would not be required.

18 Thus, the stator component, once suitably lubricated by the lubricant in the sump, provides a novel support and bearing means to orient the linearly moved rotor in the linear motor optimally within the changing magnetic fields produced at the stator.

19 The stator is, in an exemplary embodiment, formed in three parts 30, 32, 34 of substantially equal inner diameter thus forming one continuous cylinder 12 within which the rotor can fit and move, to form a two-electromagnet stator in cylindrical form into which a single magnetic field rotor in the shape of a tightly fitted piston is located, oriented and borne.

20 The outer parts of the stator are each formed of suitable material which when wound with electrically-conductive wire or similar coils 20, 22 and when said coil has a direct electrical current passing there through, will form a solenoid style of electromagnet. The magnetic field produced by said electromagnet acts upon the permanent magnet which is (or is a significant part of) the rotor, to move the rotor through the field along its axis as supported by the said stator's cylindrical inner cavity. The two electromagnetic parts of the stator are electrically and magnetically isolated from each other by a third middle part 34 which is not conductive of either power or magnetic flux, and which is mounted between the two magnetically active parts.

21 The rotor and stator thus form a piston and cylinder, respectively. At one end of the cylinder may be a sump within which lubricant is placed, and the rotor is at that end fitted with a gasket or O-ring configured such that the rotor is sealed with the cylinder, keeping the lubricant within its sump. The sump may be sealed if required to form a return mechanism for the rotor, but in an exemplary two-field stator system, may be open to atmospheric pressure but built to contain the lubricant within its cavity.

22 The rotor's other end may be configured in a number of ways to bear a work load, such as (by example) to form a piston and cylinder with suitable inlet and outlet valves to compress fluid or to pump fluid from inlet to outlet, or to evacuate an inlet to form partial vacuum, or similar loads; similarly, to that end of the rotor may be attached a drive shaft which can be operatively linked to an eccentric to convert the rotor's linear motion to a rotating drive motion, for example to a drive shaft.

23 A number of these rotor/stator driven-piston/cylinder systems can be inter-linked, for example ganged to a crank-shaft, suitably timed, to form a multi-cylinder motor.

24 The end plates may have any of various designs, for example screwed in cover caps. The coils may be made of copper wire. The non-magnetic sleeve 34 may be 2-3 cm or more in width.

25 In one embodiment, the non-magnetic sleeve 34 was 127 mm long, 44 mm inside diameter, with the end portions inserted in the sleeves 30, 32 each being 25.4 mm long and 4 mm thick, the central portion having respective thicknesses of 6 mm and 8 mm on either side of the flange 18. The corresponding piston had length 127 mm, with the bearings each being 16 mm wide, the end ribs being 4.mm wide and the other ribs and grooves each being 3 mm wide. The grooves were 3 mm deep and the sump 74 was 9 mm deep. The sleeves 30, 32 were 50.8 mm wide, with smaller ID 44.5 mm, and larger 52.5 mm, the OD being 56.5 mm. The length of the piston may be varied, and could be 152. 4 mm long for example in a housing having overall width of 177.8 mm. Width here refers to the axial direction, rather than radial. The housing may have an axial width to diameter ratio of between 2 and 3. The sleeve radial thickness may be for example from 1 mm to any suitable thickness, depending on the application. Even if the sleeve is only as thick as a film, it is believed that useful properties are obtained.

26 As shown in Figs. 6A, 6B and 6C, the linear engine may use a piston 24A that is hollow at both ends, a piston 24B that is solid or a piston 24C that is hollow at one end.

The piston can be hollow in the middle as well, and therefore provide a conduit from one end of the piston to the other.

27 As shown in Fig. 7A, a housing or enclosed sleeve 12A may be formed with axially alternating non-magnetic sections 90, for example made of ceramic, corresponding to regions of no-flux (or low flux), and magnetic sections 92 corresponding to regions of higher flux density, each fitted to an adjoining section with an annular tongue and groove design 91. The sections 90, 92, may be of any suitable width and radial thickness, providing there are alternating magnetic and non-magnetic sections. The non-magnetic sections 90 may be made of ceramic. The sleeve 12A may be used in a linear engine with a piston of the type shown in Fig. 1, with multiple coils, each coil being placed over a corresponding magnetic section 92 as illustrated in Fig. 1.

28 As shown in Fig. 7B, a sleeve 12B may be formed with cirumferentially alternating magnetic strips 94 and non-magnetic strips 96, for example made of ceramic, each fitted to adjoining strips with a tongue and groove design 95. The strips 94, 96, may be of any width, providing there are alternating magnetic and non-magnetic sections. The magnetic sections 92 and strips 94 correspond to regions of higher flux density. The enclosed sleeve 12B is used with a series of coils spaced around the sleeve 12B in conventional fashion with a conventional rotor inside. Apart from the sleeve 12B, the motor this produced is conventional, with conventional coils, power supply, bearings, bushings and rotor. The enclosed sleeve 12B is used with a series of coils spaced around the outside of the sleeve 12B in conventional fashion with a conventional rotor or stator inside.

29 It is believed that the no or low flux non-magnetic sections disclosed here help protect the coils from damage, for example from burning out. An important advantage of the design disclosed here is that it provides an integral sleeve with an integrated flux and no-flux pattern corresponding to the alternating magnetic (flux) and non-magnetic (no-flux) sections.

30 There are a number of methods of controlling the electrically current flow, duration, direction, and power characteristics, responsive to the motor's operating characteristics, its design characteristics, the load or desired power production, power available, or other means, and may be done electro-mechanically, by computational means, responsive to sensors, or self-regulating through feedback mechanisms.

31 The invention has particular application (but is not thereby limited) in the field of provision of small-volume, quiet, compressors for refrigeration and similar equipment. Larger scaled versions could be utilized as motive power for vehicles or heavier equipment, where efficiency, long-life, quietness and reliability are important.

32 The housing 12 may be arranged in a circle, in which case the piston will move around the circle, either continuously or by reciprocating within the housing. The linear engine of the present invention may be operated as a pump, compressor, motor or generator.

33 Although it is preferred that the sleeve be enclosed and continuous, there may be holes in the sleeves, providing the holes allow alternating patterns of high flux and low flux with magnetic sections separated by non-magnetic sections.. The coils may have less or more axial width (along the tubular sleeve) than the magnetic section, depending on the application, but it is preferred that the coils have the same width as the magnetic sections of the sleeve. The non-magnetic section of the sleeve only allows the coils to be separated so that they are not one coil. The lower the magnetic flux between the magnetic sections, the better, with preferably zero flux, as for example may be obtained if the non-magnetic material is superconducting.

34 Immaterial modifications may be made to the invention described here without departing from the essence of the invention.